



Dec 2012, CNNS Workshop, Livermore

COHERENT NEUTRINO- NUCLEAR SCATTERING WITH GERMANIUM

Belkis Cabrera-Palmer

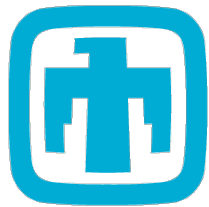
Sandia National Laboratories



ULGeN: Ultra-Low noise Germanium Neutrino detection system



- **Project Team:**



**Sandia
National
Laboratories**



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Daniel Hogan

This project aims at the development, fabrication, and deployment of a kg-scale High Purity Germanium (HPGe) detector with the required ultra-low electronic noise threshold to demonstrate detection of reactor antineutrinos via coherent neutrino-nucleus scattering.



Coherent Neutrino-Nucleus Scattering (CNNS)

PHYSICAL REVIEW D

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1 MARCH 1974

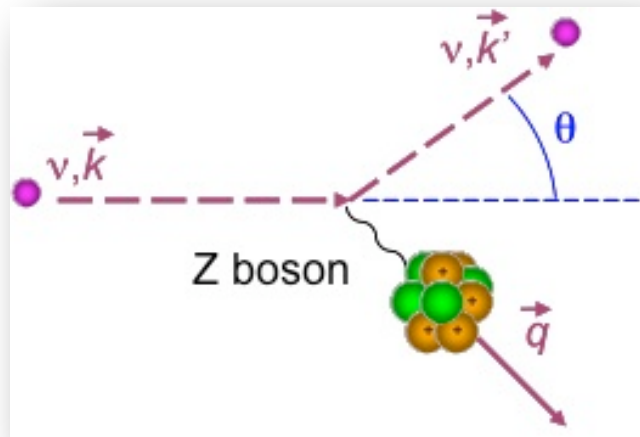
Coherent effects of a weak neutral current

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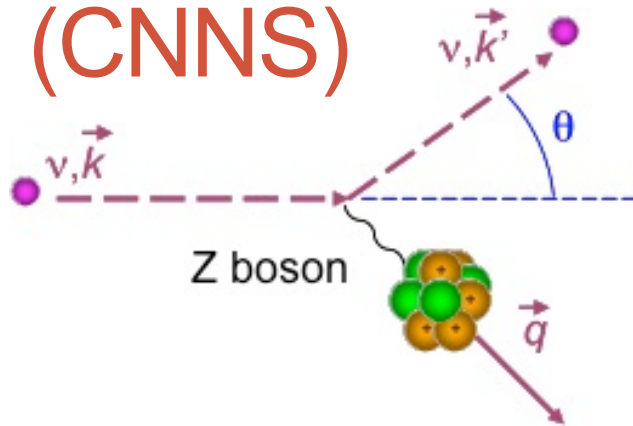
(Received 15 October 1973; revised manuscript received 19 November 1973)



... The idea is very simple: If there is a weak neutral current, elastic neutrino-nucleus scattering should exhibit a sharp coherent forward peak characteristic of the size of the target just as electron-nucleus elastic scattering does...

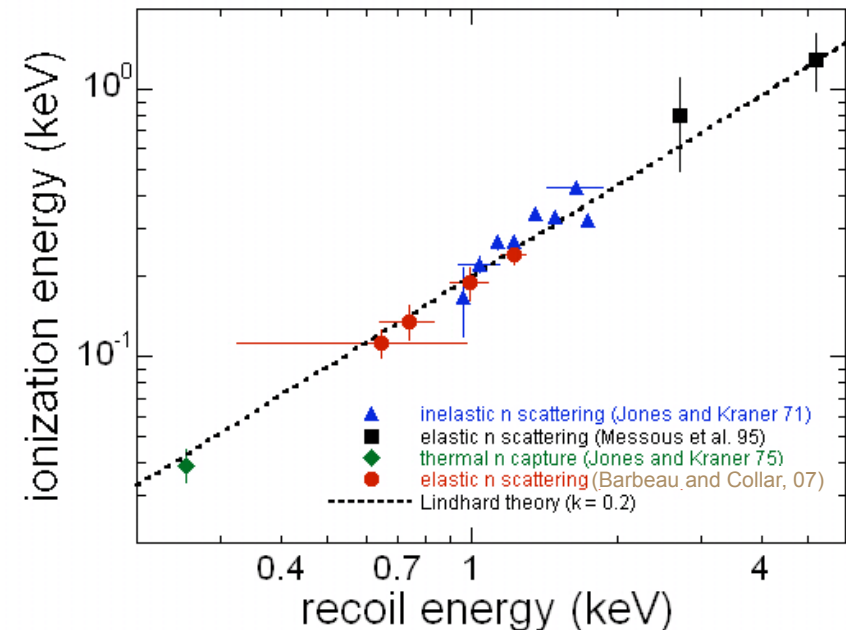
- It has never been observed!

Coherent Neutrino-Nucleus Scattering (CNNS)



- Cross section enhanced by N^2
- Detection of nucleus recoil with transfer momentum $q \ll 1/(\text{nucleus radius}) \sim \text{tens of MeV}$ (condition of coherence)
- Recoil energy
$$\leq \frac{2}{A} \left[\frac{E_v}{1\text{MeV}} \right]^2 \text{ keV}$$

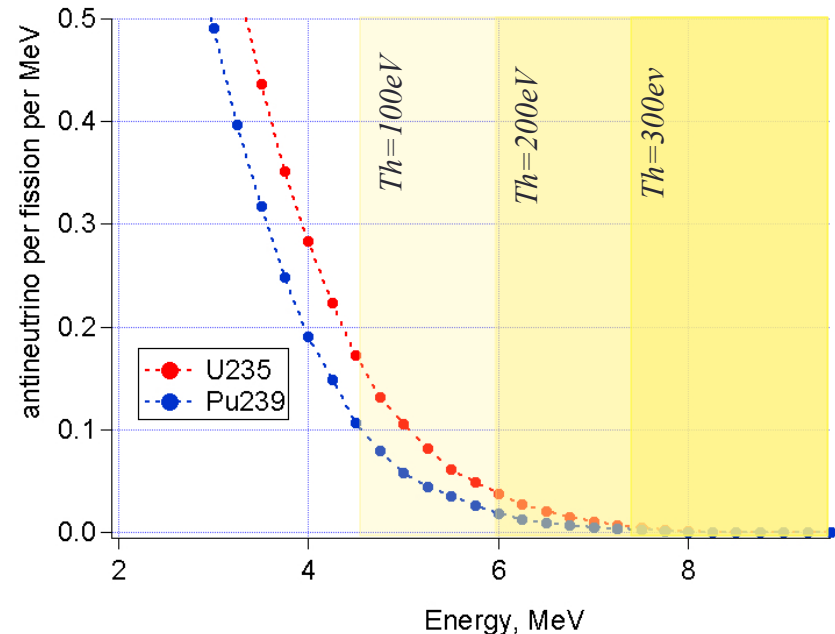
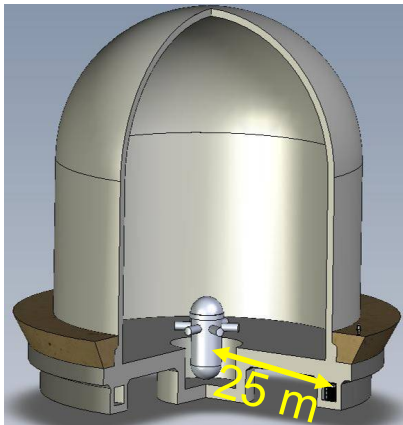
- ▶ Reactor antineutrinos produce Ge recoils of $< \sim 3\text{keV}$
- ▶ Quenching to $\sim 20\%$ of the recoil energy
- ▶ \rightarrow detection of ionization signal **$< 600\text{eV}$**



Reactor Antineutrino signal vs. HPGe threshold

- Very low event rate largely dependent on energy threshold, target mass and distance to core

Ge detector Threshold (eV)	CNNS counts / day kg at 25m from core
300	~0.08
200	~0.60
100	~5.01

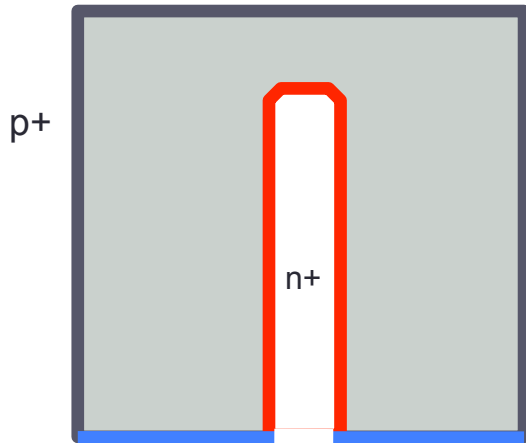


- Detector threshold imposes a kinematic constraint on accessible reactor antineutrino energies $E_v^{\min} \sim \sqrt{\frac{A * Threshold(keV)}{2 * QuenchingFactor}}$
- More-energetic antineutrino sources ($E_v \sim 30\text{MeV}$) admit higher detector threshold

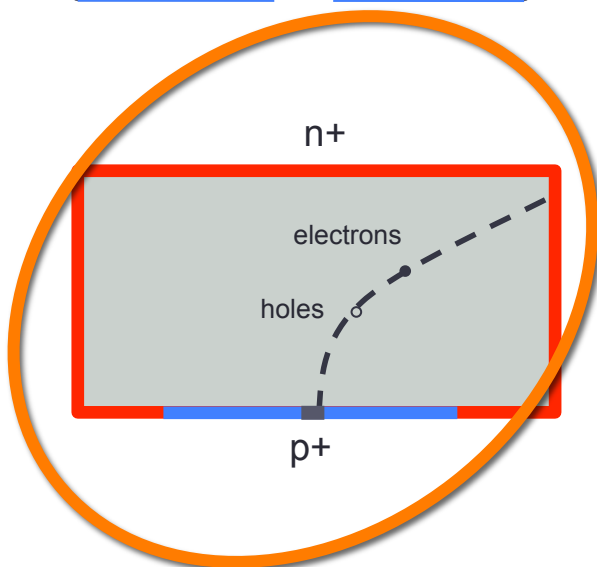


Electronic threshold

Lower electronic threshold with Point-Contact HPGe detectors

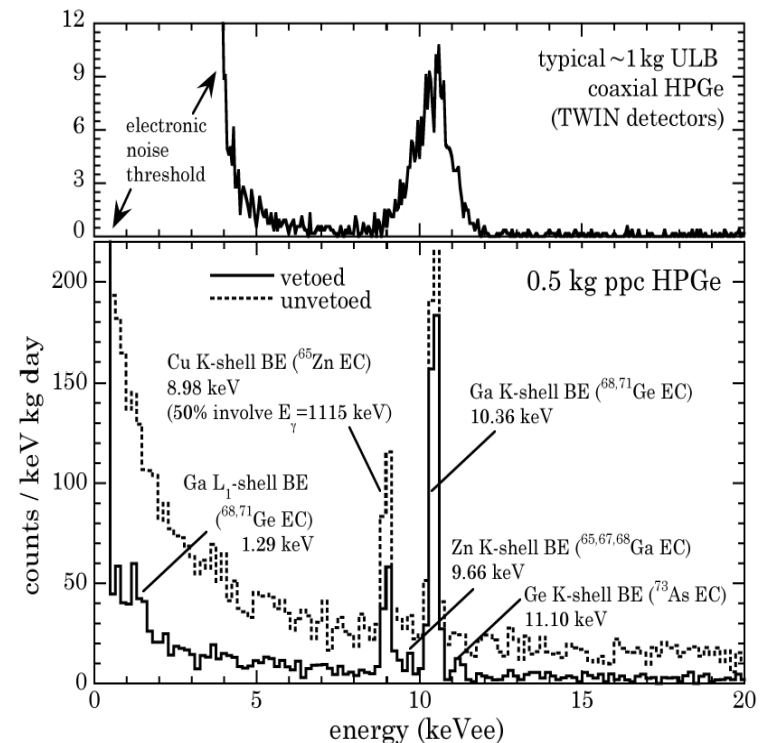


- Coaxial
- Electronic FWHM $\sim 2\text{keV}$
- $\sim 1\text{kg}$
- $C \sim 20\text{pF}$



- Point-contact
- BEGe's produced by CANBERRA INC
- Electronic FWHM as low as $\sim 150\text{eV}^*$
- As large as $\sim 0.8\text{kg}$
- C of order of 1pF

- Decrease capacitance to lower noise threshold and improve resolution

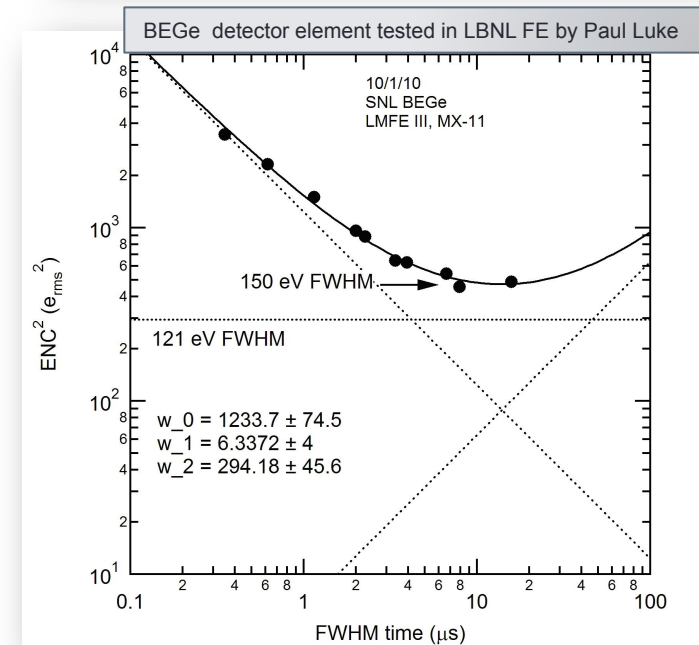
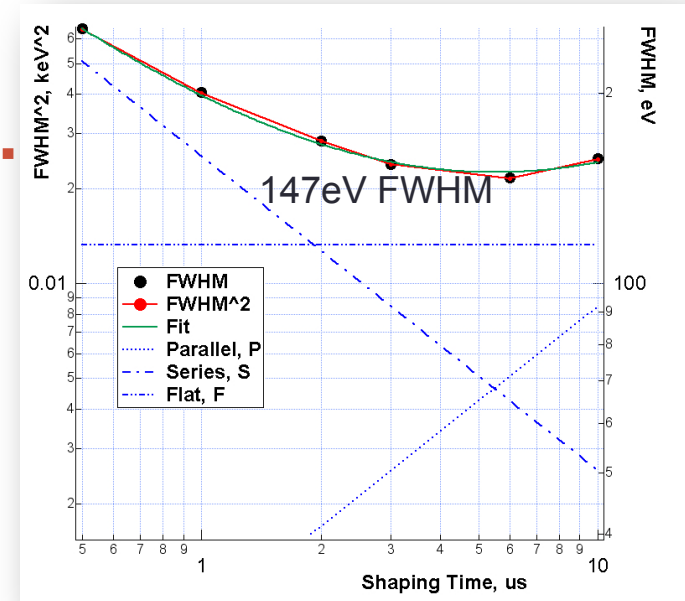


Aalseth *et al.* PRL 101, 251301 (2008)



We started with a BEGe...

- Mass $\sim 0.82\text{kg}$,
 - Point-contact diameter $\sim 5\text{mm}$,
 - Capacitance $\sim 1.5\text{pF}$
 - From CANBERRA: 147eV FWHM
-
- **Expected threshold 350-450eV: still too high for CNNS detection**
 - **SPICE analysis:** Negligible contribution from preamp and High Voltage circuits
 - **→ noise mainly from detector element and Front-End (FE) electronics**
 - **Detector element tested in LBNL Front-End:** all noise components are identical in two very different FE assemblies
 - **→ noise mainly from the detector element**
 - **→ path to lower noise: decrease capacitance again by reducing the point contact size (See Paul Barton's talk)**



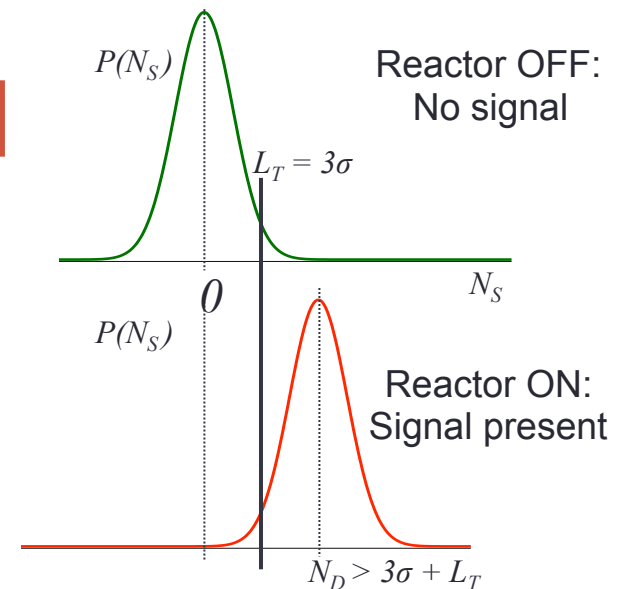


Background

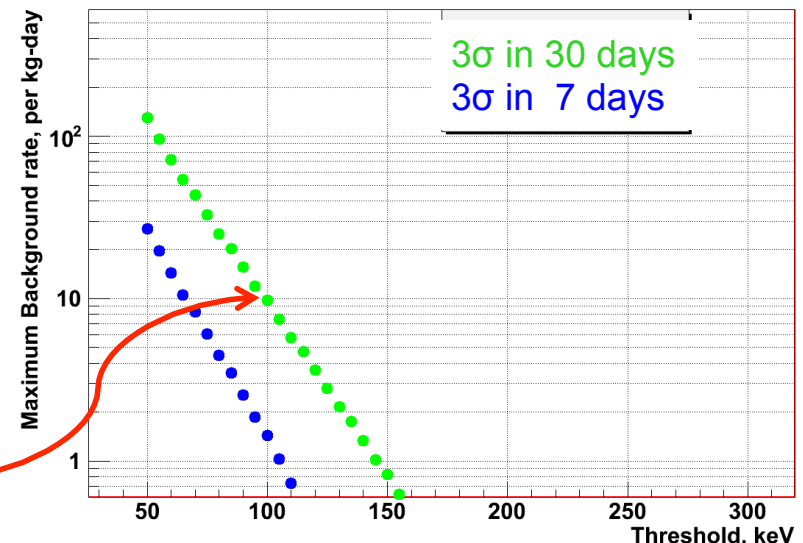


Threshold vs. Background

The background rate and measurement time (e.g., 7days or 30days), set the required electronic threshold to achieve a 3σ -confidence level measurement of reactor status ON vs. OFF



- The plots show an estimation of the maximum background rate (per kg of Ge, per day) integrated from threshold to 1keV, that would allow a 3σ observation of reactor ON/OFF transition, versus energy threshold.
- A 100eV threshold admits no more than 10 bckg counts/kg-day in the region $< 1\text{keV}$





Background signals < 1keV

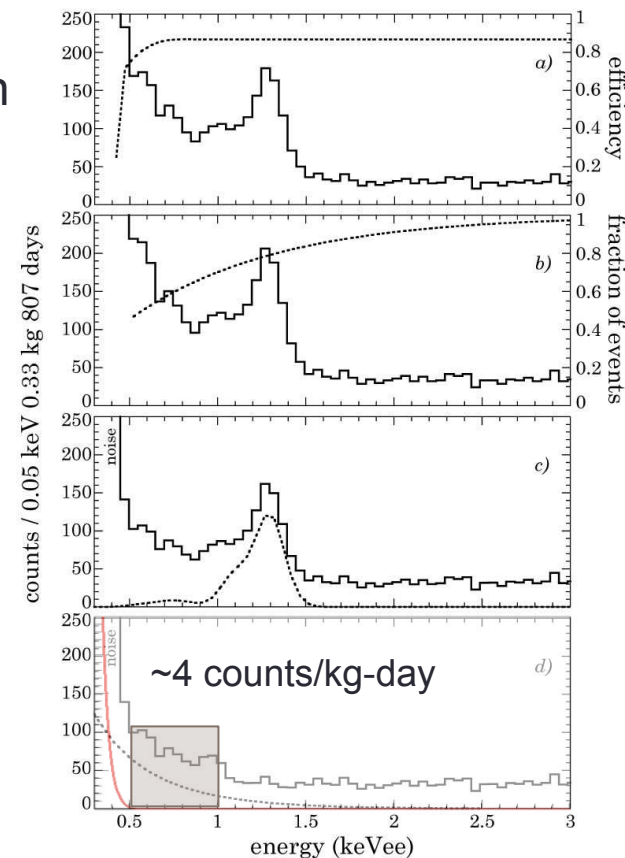
Primary particle	Process	Background signal
Cosmic secondary n and μ -induced n	Scattering off Ge nucleus	Ge-nucleus recoils
Cosmic secondary n and μ -induced n	Nuclei activation: ^{71}Ge , ^{68}Ga , ^{65}Zn , ...	Partial energy depositions from X-rays and Auger e-, internal to germanium
Cosmic primary p at sea level	Nuclei activation: ^{73}As , ^{68}Ge , ...	
Thermal n	Nuclei activation: ^{71}Ge	
γ	Natural radioactivity from detector materials	Forward-peaked Compton scattering
Solar and Geo ν	Scattering off Ge nucleus	Ge-nucleus recoils
WIMP ?		



Measured backgrounds from other experiments: underground mine

CoGeNT 2012 data: CANBERRA BEGe , 330 g of fiducial volume, 163eV FWHM, deployed in Soudan mine at 2,100m.w.e.

- Threshold 0.5keVee
- Near-threshold counts: $\sim 8 \text{ keV}^{-1} \text{ kg}^{-1} \text{ d}^{-1}$
- Irreducible counts (after all cuts) in region 0.5-1keVee: $\sim 4 \text{ kg}^{-1} \text{ d}^{-1}$
- Confirmed that decays from cosmogenic activation internal to Ge populate the region $< 3 \text{ keV}$. (Use cosmogenic peaks for calibration.)
- Partial energy deposition events (from nuclei decays) are significant near threshold but can be efficiently rejected by “risetime” cuts.
- Natural radioactivity from materials near the detector is estimated to be negligible.



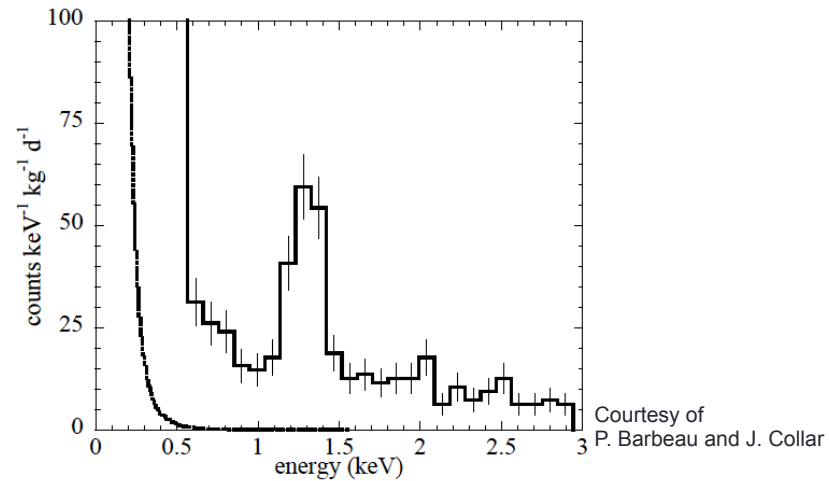
Aalseth *et al.* arXiv:1208.5737



Measured backgrounds from other experiments: SONGS Tendon Gallery

SONGS 2009 data: same CANBERA BEGe, deployed in SONGS reactor at 25m.w.e.

- Near-threshold counts: **$\sim 22 \text{ keV}^{-1} \text{ kg}^{-1} \text{ d}^{-1}$**
- Counts in 0.5-1keV range: **$\sim 11 \text{ kg}^{-1} \text{ d}^{-1}$**
- “Risetime Cuts” not applied here because the raw preamplifier traces were not recorded, but x2-3 reduction expected.
- No evidence of significant increase in neutron background at this overburden with proper shielding.



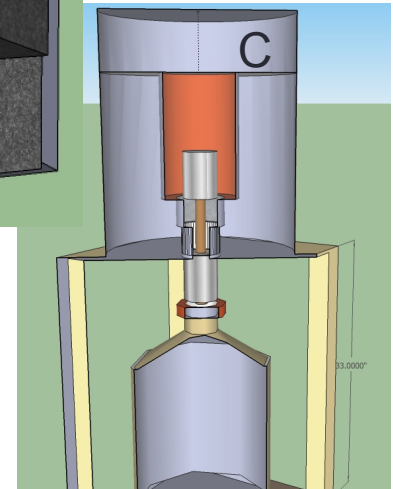
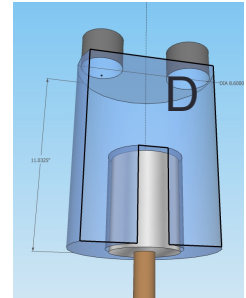
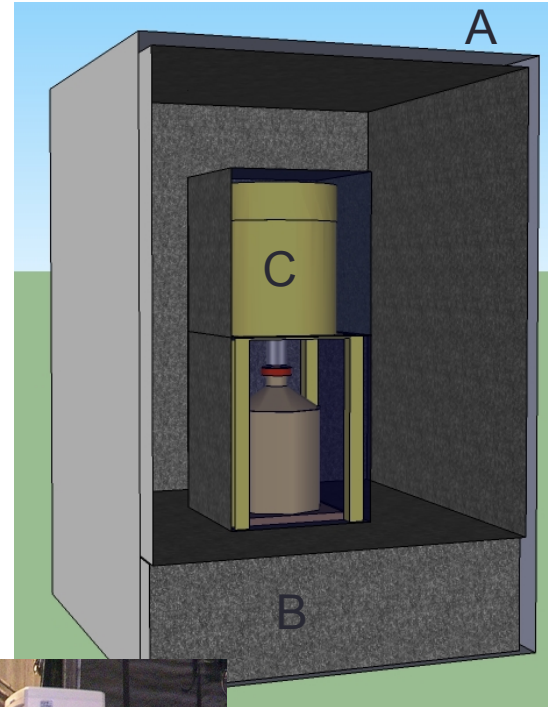


Proposed shielding

- A. 2" external muon veto
- B. 20" HDPE neutron moderator with internal 2" borated Poly as thermal neutron absorber
- C. Ultra-low background Canberra Lead shield
- D. Anticoincidence veto for fast neutrons and gammas

And also:

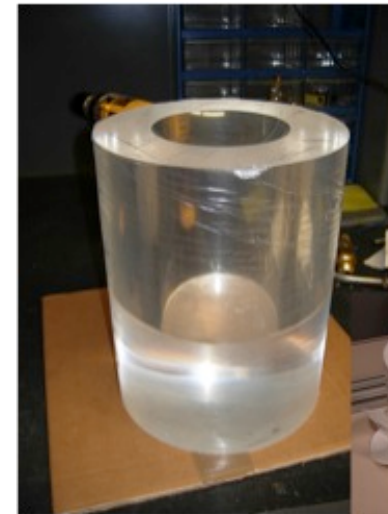
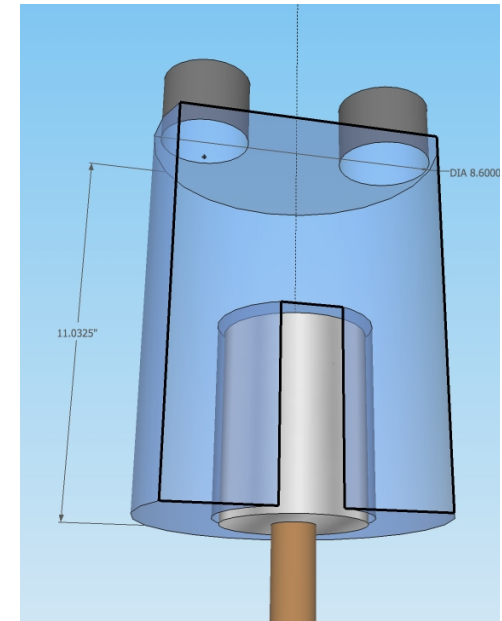
- 30 m.w.e overburden
- Radioclean detector and shield materials
- Purging Radon with nitrogen gas
- Lithium-diffused n+ contact covering most Ge surface electrode (*in p-type a ~1mm-Li layer suppresses betas and alphas from surrounding materials*)
- Time to cool down of Ge activation from exposure to surface cosmic rays



- Working on background simulations to validate shielding design

Anticoincidence veto

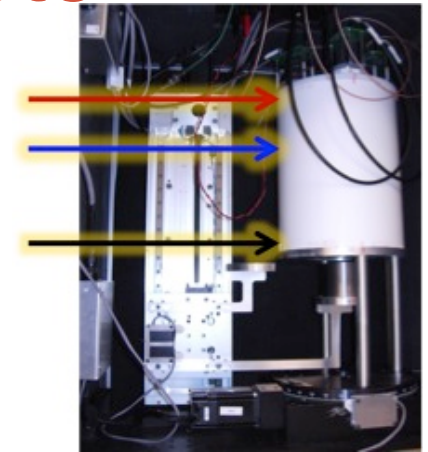
- Neutrons penetrating the external shield, if unvetoed, could create a ubiquitous background in the near-threshold energy region.
- Built and characterized an anticoincidence internal veto, made of plastic organic scintillator (PS) in order to increase sensitivity to neutrons in the vicinity of the HPGe detector..
- Inside Lead shield: Cylinder with internal well made of EJ200 PS, surrounded by GORE® Diffuse Reflector, plus 4 low-bkgd Hamamatsu PMTs, signal and HV cables
- Other experiments use inorganic scintillators like NaI(Tl) and CsI(Tl), which have high sensitivity for gammas but not for neutrons. CoGeNT at Soudan did not use AntiCompton veto.



Testing PS Anticoincidence veto

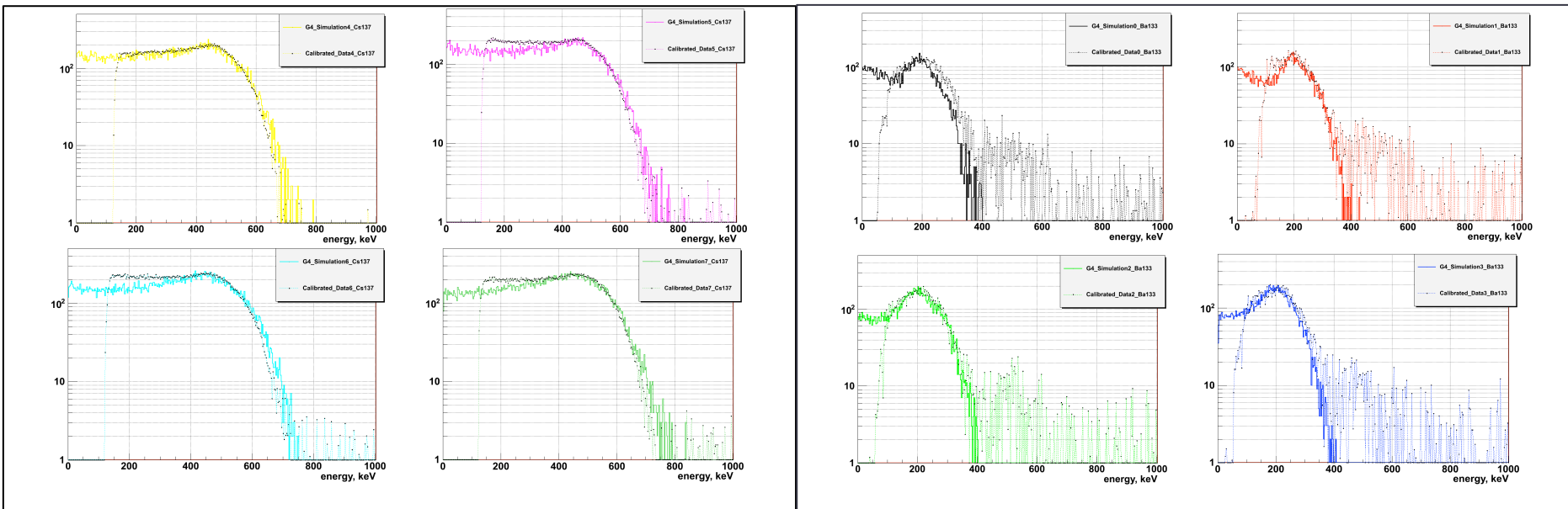
- G4 simulations of particle interaction, scintillation, and optical propagation, compared to measurement of vertical scan with ^{137}Cs and ^{133}Ba
- Results: good spatial uniformity in light collection efficiency

Vertical scan with ^{137}Cs and ^{133}Ba



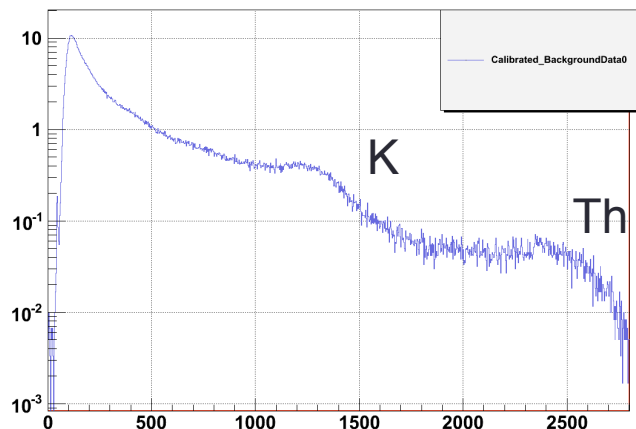
^{137}Cs source at 25.4mm (yellow), 101.6mm (pink), 177.8mm (blue), and 254.0mm (green). Black dots are data.

^{133}Ba source at 25.4mm (black), 101.6mm (red), 177.8mm (green), and 254.0mm (blue). Black dots are data.

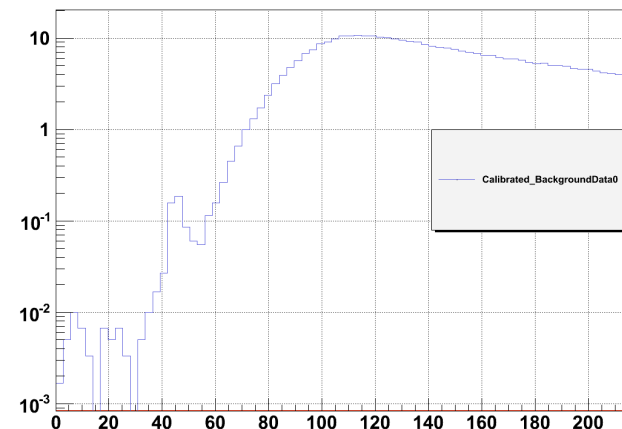


Testing PS Anticoincidence veto

- Well defined K and Th Compton edges: good energy resolution thanks to high reflectivity of the GORE® Diffuse Reflector
- Results: hardware threshold at ~100keVee
- Threshold for neutrons ~ 1MeV

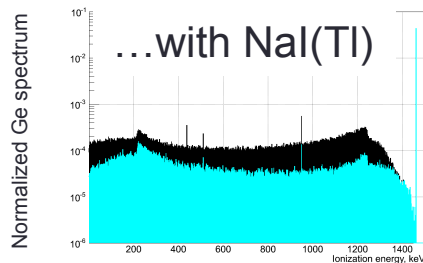
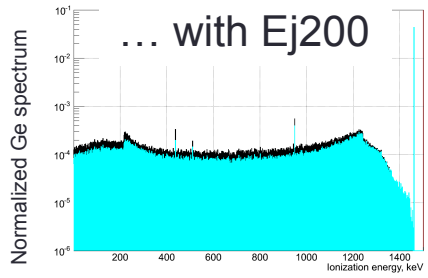


Energy Histogram of ambient background, showing the K and Th Compton edges.

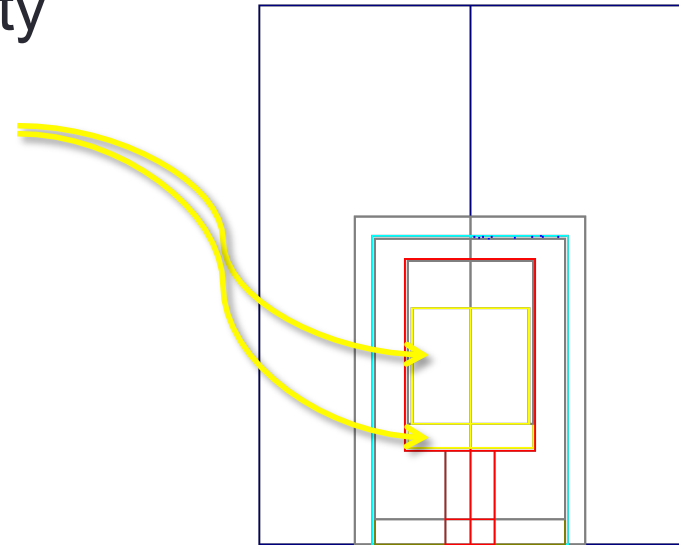


Anti-Compton efficiency: Ej200 vs NaI(Tl)

- G4 simulation of K40 radioactivity from Teflon lining and isolation



Black: all Ge counts
Blue: Ge counts with AC suppression

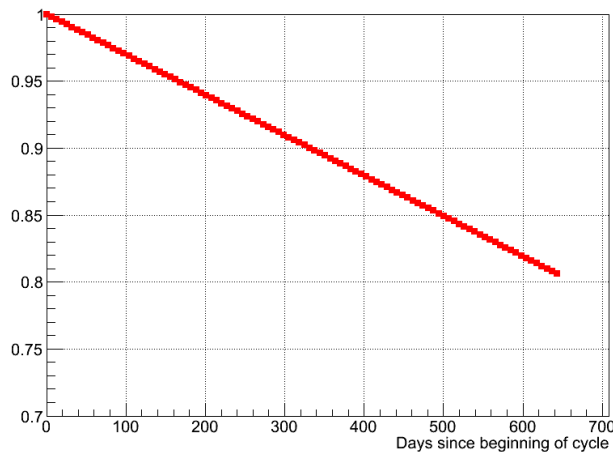


- Anti-Compton rejection efficiency degraded by $\sim 1/2$ with Ej200 compared to NaI(Tl)
- Care in choosing low radioactivity materials, including the materials for Front-End and the veto itself

	AC efficiency Full range	AC efficiency 0.1-3 keV
Ej200	0.20	0.31
NaI(Tl)	0.55	0.73

Why a Germanium detector for Reactor monitoring?

Change in CNNS signal rate from reactor anti- ν vs. fuel cycle



- About 20% variation in total **C(anti)NNS** events during NPP fuel cycle: higher sensitivity to fuel composition than inverse beta (10% variation)
- Cryogenic germanium detectors are already well known and are frequently used at nuclear reactor facilities around the world.
- Little or no safety concerns from the facility operators.
- In addition, the ability to shrink the active detector from 1 ton of scintillator material to something on the order of 10 kg of germanium might allow for much more flexibility in finding locations suitable for detector installation.



Summary

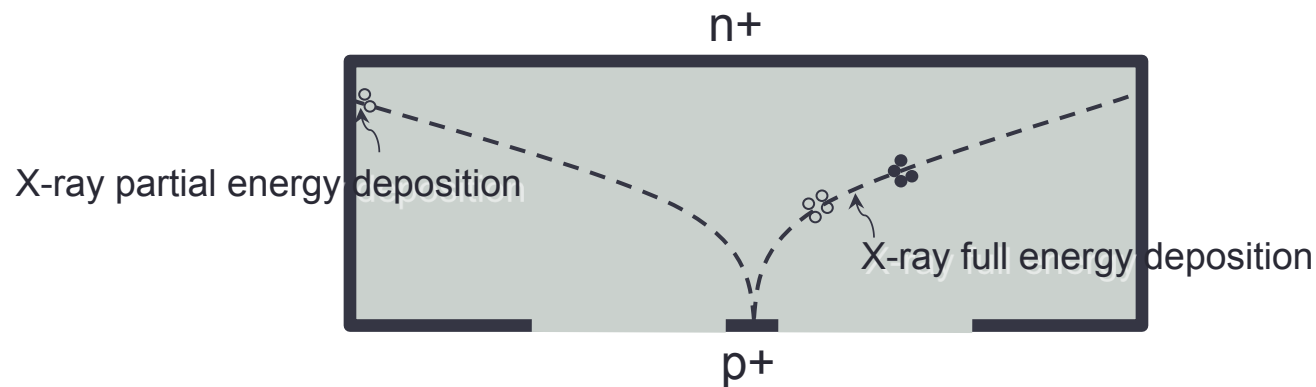
- Electronic noise threshold is the main barrier for reactor monitoring with PPC HPGe detectors. Our initial tests indicated that a path to lower noise is smaller capacitance (next talk)
- Measured background (CoGeNT2012, SONGS2009) “allow” possible observation of CNNS (reactor ON/OFF) with 100eV electronic threshold and proper shielding.
- ULGeN (LBNL-SNL-UCB) currently working on the development and towards the deployment of new 1-kg detector PPC HPGe



Backup slides

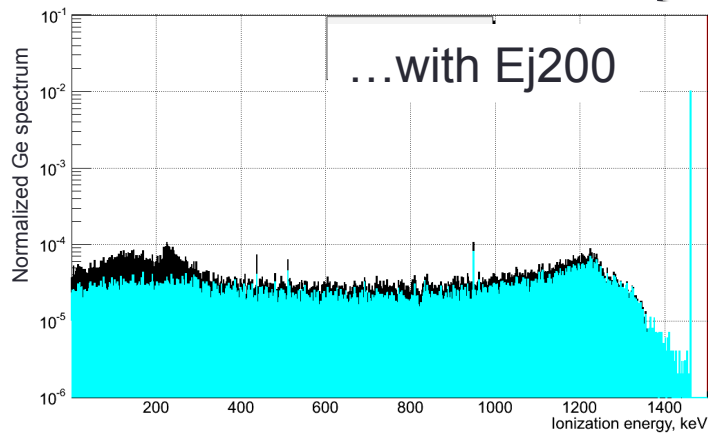
How “Risetime” cuts work

- Events near the dead region will only deposit part of the energy
- But also, the induced charge in the electrodes will rise slowly because near the dead layer the electric field is weak

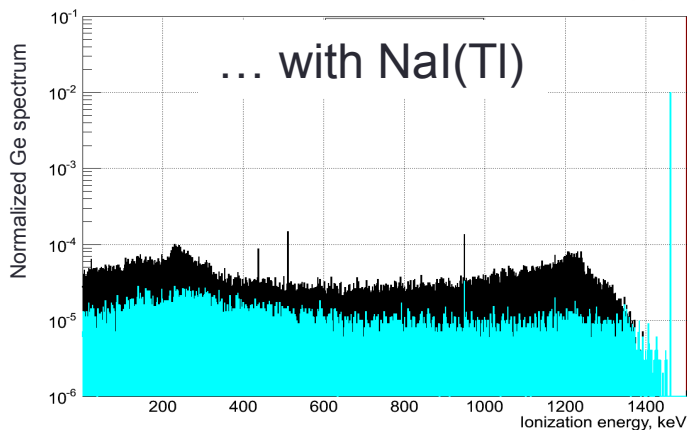
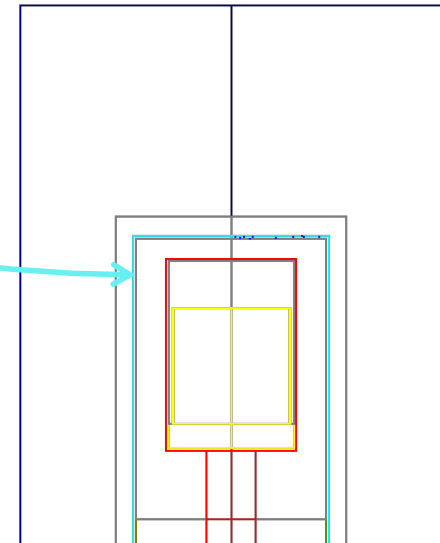


AntiCompton efficiency: Ej200 vs NaI(Tl)

- G4 simulation of K40 radioactivity from Aluminum Cap



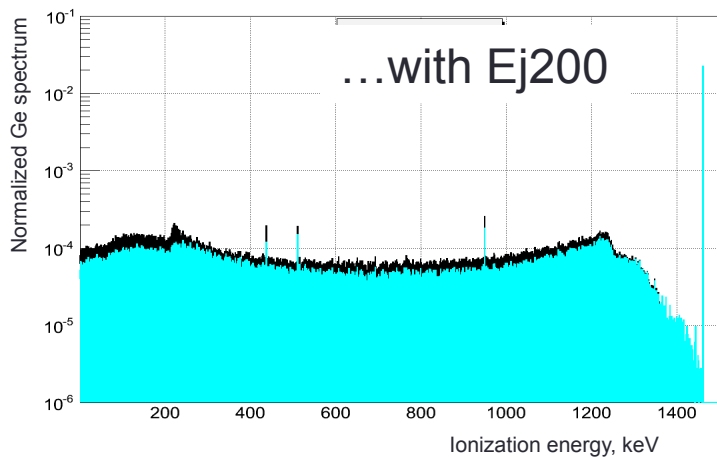
Black: all Ge counts
Blue: Ge counts with AC suppression



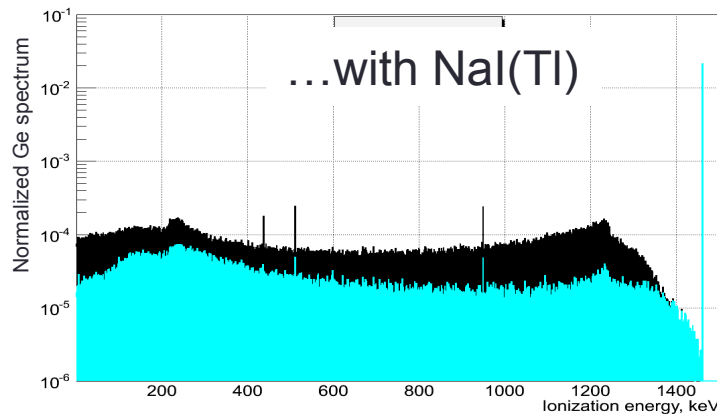
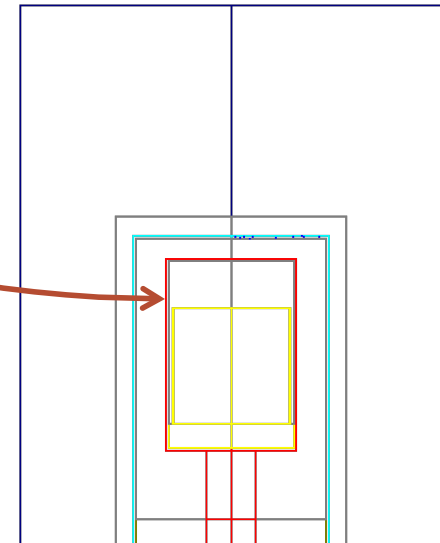
	AC efficiency Full range	AC efficiency 0.1-3 keV
Ej200	0.28	0.49
NaI(Tl)	0.60	0.75

AntiCompton efficiency: Ej200 vs NaI(Tl)

- G4 simulation of K40 radioactivity from Copper Can



Black: all Ge counts
Blue: Ge counts with AC suppression



	AC efficiency Full range	AC efficiency 0.1-3 keV
Ej200	0.21	0.33
NaI(Tl)	0.55	0.79